DOCUMENT RESUME

ED 059 897 SE 013 387

AUTHOR Handler, Philip
TITLE In Defense of Science.
PUB DATE May 71
NOTE 31p.; Presented at the General Meeting of American Iron and Steel Institute, New York, May 26, 1971 (79th)

EDRS PRICE MF-$0.65 HC-$3.29
DESCRIPTORS *Demography; Energy; *Environmental Influences; *Medicine; *Natural Resources; Physiology; *Research Needs; Scientific Research; Social Factors; Speeches

ABSTRACT

Although there are social pressures for the control of science, forcing a redirection to "relevant" problem solving tasks, the future needs are, in essence, unpredictable in detail. For this reason fundamental research is necessary to provide the appropriate base for the new technologies that human society will need. Even to solve the present problems, fundamental research approaches are needed to provide the information base that can be used technologically to maintain the ecosystems in a satisfactory state. There are faults with the present mechanisms of supporting basic scientific research, and new mechanisms need to be developed for the effective utilization of Federal funds. In addition, the economic, social, moral and political implications of scientific research need to be considered as important, but not the only determinants of scientific policy. (AL)

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IN DEFENSE OF SCIENCE

by

Dr. Philip Handler

President, National Academy of Sciences

The twenty-fifth Charles M. Schwab Memorial Lecture was prepared for presentation at the 79th General Meeting of American Iron and Steel Institute, New York, May 26, 1971. Dr. Handler's speech was received too late for distribution in pre-printed form.

SE 013 387

As I began to prepare this lecture, I contemplated a discussion of some of the problems in which I assumed your central interest must lie: productivity, loss of overseas markets, competition at home with foreign technology and labor costs, technological unemployment, federal responsibility for the state of the economy, etc. But I soon realized that others here would discuss these matters in great detail and out of greater personal knowledge. Accordingly I chose, instead, to address you as leaders of the American people, opinion makers across our land whose assistance I now seek in defense of science.

Only yesterday, no such defense seemed required. The tinkering, inventor folk-heroes of yesterday -- the Wrights, Morse, Bell, Edison, Ford -- had been replaced in part by a new set of household names -- Einstein, Oppenheimer, Watson and Crick. Science-based technology was accepted as a cornucopia from which only good could flow and it seemed that Toynbee had indeed expressed the modern credo, "Our age will be remembered because it is the first generation in which mankind dared to believe it practical to make the benefits of civilization available to the whole human race."

Suddenly, we are confronted with the vision of science and technology as a modern Janus -- a two-faced god. We are told that when we think of atomic energy we should envision apocalyptic nuclear extermination, radioactive wastes and harmful genetic mutations; that heavy industry -- yours -- equates to pollution of air, rivers and streams; that fertilizers, insecticides, and pesticides developed for agricultural productivity and health protection bring contamination of our food and of earth itself; that mass-produced personal transportation is the major source of air pollution; that the educational potential of television has been transmuted into the idiot-box of crass commercial materialism; that the wonders of the new pharmacopoeia evoke only visions of malformed infants; that what I considered to be the triumphal selection of foodstuffs in every supermarket conveys possible carcinogens and mutagens; that micro-miniaturization of electronics, the heart of the modern computer, connotes loss of privacy and a depersonalized machine culture; that our growing understanding of the human brain and of genetic mechanisms can bring tyranny; that sanitation and medicine bring overpopulation and human degradation; that steroid contraceptives promote licentiousness and destruction of the family.

These views were brassily stated by Paul Goodman, "Inevitably, given the actual disasters that scientific technology has produced, superstitious respect for the wizards has been tinged with a lust to tear them limb from limb." From that standpoint it seems that "Do not fold, spindle or mutilate" refers not to IBM cards but to human beings.

More reasonably, according to Harwood, "Science and technology must not be rampant, irrepressible forces to which man must meekly submit. The challenge is not where technology is blindly leading us, but how can science and technology help get us where we want to go?" He asks, "Through which code of morals can society exploit and control science and technology, not only to assure physical survival and material comforts, but to assure the survival of human values and the more equitable betterment of mankind. Does a basis for such moral values reside intrinsically within the practice of science itself?"

Ethics and Morals

No society can survive without value standards and an ethical system, yet thoughtful scientists consider that no existing system, no revealed religion, no 19th Century rationalistic philosophy, neither Marxism nor

existentialism can sustain man in the modern world. Jacques Monod's contention is that older value systems wither into absurdity when confronted by that science which reaches truth by confrontation of logic with experience. But Monod offers no substitute ethic.

From the personal standpoint of the scientist, these matters were summarized in part by Warren Weaver, "Science is not technology, it is not gadgetry, it is not some mysterious cult, it is not a great mechanical monster; science is an adventure of the human spirit. It is an essentially anarchistic enterprise stimulated largely by curiosity, served largely by disciplined imagination and based largely on faith in the reasonableness, order and beauty of the universe of which man is part."

Science is more than just a record of observations and empirical fact, it is knowledge organized in such fashion as to permit insight into all natural phenomena and forces, so that, from the relatedness of facts it creates unity out of diversity. It is this recognition of connections -- were none appeared to exist before -- that is the essence of scientific creativity. Although the requirements of precision

and logic, the necessity of conforming to facts, the methodology of testing of concepts and ideas, may create the impression of scientific activity as an impersonal exercise, nothing could be farther from the truth. Science is a truly human experience, it progresses because of the pleasure and excitement of personal involvement which underlies scientific creativity. But that does not constitute an ethos.

A scientific ethic <u>can</u> be described, albeit in retrospect. It would include personal independence in observation and hypothesis, regardless of established dogma; free inquiry and dissent but at least temporary acceptance of the common fund of accepted knowledge; free communication of both observation and interpretation; open-minded willingness to consider revision of older doctrine.

This ethic derives from the necessities of science itself no alternative is available as a means to objective knowledge. But, restated, these are also the central values of our civilization: dignity, freedom, justice, democracy, our cherished moral values, are so much a part of the scientific ethic that Bronowski surmised that if such values had not previously existed, the scientific community would have had to invent them.

The Attack on Science

Current public concern for science, then, lies with its interaction with society through technology. Scientists generally have agreed with Glenn Seaborg, that "Knowledge is born without moral properties. It is man who applies it according to his acquired pattern of behavior. Man, not knowledge, is the cause of violence." But that is too facile. If it be true that "science is what scientists do," then the latter cannot escape the responsibility to make known the conceivable consequences of their newly gained understanding when they have the foresight and wisdom to so do. That is why after Hiroshima, Robert Oppenheimer said that, "For the first time, the scientist has known sin." What then is the nature of current public concern for science?

1. A perpetual problem is public failure to distinguish between science itself and misuse or abuse of the technology it makes possible, whether that be seen as unpredicted effects on population, the environment; or the arms race.

2. Once again some proclaim that most of the important work of science in revealing the nature of the universe, including that of man himself, has already been done. Such predictions have been made in the past -- and always

belied by subsequent history. There is little reason to think otherwise today. Certainly no biologist seeking to understand man as an organism or sociologist seeking to understand man the social creature, no astronomer concerned with cosmology, no theoretical physicist could accept such a view. Nor could those who struggle to improve a thousand useful technologies.

3. It is difficult to assess the public impact of the rise of those cults which emphasize the affective aspects of human experience rather than the cognitive and analytical who demand instant gratification of their needs and desires. How disconcerting it is that our society supports at least 30 times as many astrologers as astronomers! Nor can we estimate the future impact of those movements which would diminish public esteem of the components of our high culture, of which science is a part, romanticizing the underprivileged and promoting the egalitarian, when science is necessarily the activity of a special elite. I no more understand what is called "science for the people" than I know what is meant by the "age of Aquarius." But when we are portrayed as the "mad scientists" of television or are seen as individuals who may speak mathematics or chemistry, who

use English itself in strange ways, the xenophobia inherent in every culture generates distrust by reflex.

4. The scientist may find deep satisfaction in statements like that of Sir Brian Flowers', "Science, like the arts, gives expression to the innermost yearnings of the human spirit and thereby enriches our lives. It changes profoundly our comprehension of the world around us and of our place in it." But that satisfaction is shared by a very small fraction of our population. The conservatism of social systems, necessary for mere survival, retreats from the vastness and hostility of the cosmos revealed by modern astronomy, from the suggestion that, one day, man's brain will be totally comprehensible in physical terms; from the allegation that, biologically speaking, man is more closely related to the chimpanzee than is the horse to the donkey. It is unlikely that such thoughts would lead to declining public support for science or diminished numbers of students seeking scientific careers, but they do contribute to an increasingly unfavorable climate for public consideration of the claims of science on the public purse, exacerbating the current malaise of science.

5. And, of course, there is the tiresome complaint that fundamental research is becoming progressively more abstract, more irrelevant to society. Strangely, those who

make this statement also request unprecedented control of science for the preservation of the good life -- in which case, I fail to see why irrelevant activities need rigid control. Patently, those who make such claims fail to appreciate the process by which successful innovation arises from continuing interplay between fundamental and applied research, and fail to appreciate the long lead time -- no less than a decade -- for translation of scientific findings into societally useful technology.

6. How much we have accomplished since World War II! That now we may find it wanting, if some of our accomplishments turn to ashes in our mouths, reflects not failure of science or its adaptation to technology, but a yet more rapid alteration of our goals, as they were previously perceived, the societal equivalent of the "floating aspiration level" of individual humans. (That means only that we all spoil easily upward!) Many young people find themselves dissatisfied; they hold visions of ill-formed, vague new goals. And if those are someday to be met we shall surely require technologies based on yet more knowledge, but as yet unspecifiable. Hence, if currently perceived social goals, no matter how vague, are utilized as the measure of the "relevance" of the research endeavor, then, if the past is any guide, the scientific community would be behaving as, it is

claimed, generals do when they "prepare for the last war." It is precisely because, a decade hence, our goals will again have changed, that nothing can be more relevant to the future than undirected fundamental research which simply must occupy a substantial fraction of the scientific community if we are to be positioned to cope with that unknown tomorrow.

7. A small but vocal tide of concern suggests that some aspects of science are best left unexplored, a movement which has two aspects. We have already referred to the chronic resistance to the intrusion of new knowledge which might substantially alter previously held views. This was well expressed by Eddington in his *The Nature of the Physical World*, "We are drawing near to the great question whether there is any domain of activity -- of life, of consciousness, of deity, which will not be engulfed by the advance of exact science; and our apprehension is not directed against the particular entities of physics, but against all entities of the category to which exact science can apply. For exact science invokes, or has seemed to invoke, the type of law, inevitable and soulless, against which the human spirit rebels. If science finally declares that man is no more than a fortuitous concourse

of atoms, that blow will not be softened by the explanation that the atoms in question are the Mendelian unit characters (we now call these genes) and not the material atoms of the chemist."

The other aspect of this problem has emerged in public repugnance at the possibilities of "genetic engineering," including production of multiple copies of a single individual by the technique called cloning. Quite apart from the present remoteness of that possibility, the fact remains that book-burning was ever evil; resistance to the advance of science at its exciting frontiers is its modern equivalent and not only delays progress, it erodes the moral fiber of civilization, a precious, fragile veneer over our animal state.

It will, of course, remain for society, collectively, to manage the manner in which the information so gained is to be used. Scientists, no less than others, are repelled by the image of a world populated by multiple copies of idiot laborers, football players or soldiers, or even of Einstein or Mozart for that matter. Nor have we any taste for mass manipulation of the population by the utilization of mind-altering drugs. But society must surely protect the right of sci-

ence to undertake those experiments by which genuine information and understanding might be acquired, just as society must subsequently determine how such knowledge shall be employed.

8. There is growing concern for the history of cooperation between the scientific community and the military. Pondering nuclear, biological and chemical weapons, those espousing the extreme view argue that since new knowledge is most easily available to those with political and economic power, acquisition of new knowledge must inevitably lead to further concentration of that power and, thus, must be inherently evil. Those who so hold, according to Harvey Brooks, have replaced the adage "the truth shall make you free" with the slogan "beware of the truth, for it can be used to enslave you," a naive conspiratorial view of our society.

A rather different aspect of the relationship between the military and the scientific community may have had insufficient attention. For well known historical reasons, the earliest federal sponsor of scientific research on the current scale was the Department of Defense. That support remained essentially unchallenged until Senator Mansfield pressed for support, by the military, of only those scientific projects which can be shown to have an

immediate relationship to military needs. Those closest to this problem believe that it would be tragic if rigid implementation of that philosophy were to result in a clear separation of the military from the very best of the domestic technical community. They believe, as do I, that while we require a Defense Department, as we do, let it be competent.

On the other hand, we may have already paid some price for the arrangement, understood by all concerned, whereby support of a great deal of fundamental research has been underwritten by the Defense Department with little or no reference to the immediacy of its application. This has advanced many areas of science, notably solid state physics, while the funds so used were probably made available with no reduction in the funds which otherwise might have been made available to the Defense Department. The cause of progress in science and its applications to both military and domestic problems was certainly served thereby.

What is not measurable is the influence this history may have had on the attitudes of an entire generation of physical scientists and engineers who, albeit all unwittingly, cannot help but regard the policies and programs of the Defense Department somewhat more sympathetically,

less objectively, than might otherwise have been the case. The possible consequences of this situation are uncertain but warrant attention.

9. This may be translated into the frequently debated question of what fraction of the national research endeavor should be funded through a central research authority -- as in Britain -- and what fraction through mission agencies. I insist that a substantial portion of the research effort, even on campus, should be funded through the mission agencies both so as to enhance their mission capability and assure awareness of agency problems among the external technical community. But I also believe that we have overdone this and that we should look to the day when an adequately funded NSF -- or its equivalent -- provides about one-half of the federal support of basic research.

10. One other lesson may be drawn from this history. The magnitude of funding of academic science from a variety of agencies has delayed the day when the federal government must accept responsibility for the fiscal stabilization of the universities. This responsibility is still being met in part by local "bootlegging" of federal funds appropriated for research, thereby further

delaying the long overdue stabilization of the financial base for both private and state institutions of higher education.

11. It is frequently stated that if science is to find support from the public exchequer at a level greater than that which it would receive as a purely cultural endeavor, there is a continuing burden to demonstrate its relationship to societal need. As we have seen, however, that relevance must really relate to as yet unperceived need. Hence, it is impossible to plan and can only be evaluated in retrospect.

Nevertheless, those who would further the cause of science must understand that, whatever the past, however glorious and uplifting some of us may find the intellectual edifice of science, as Don Price has noted, it can be protected against attack only with the understanding that, whereas science cannot determine the values which direct political choices, science cannot be totally irrelevant to them. This understanding must be particularly clear to those encharged with support of the social sciences which are, as yet, institutionally weaker than are the natural sciences. I become particularly alarmed when the cry for relevance, by students and others, threatens to reorient universities, the repositories of disciplinary competence, so that they shall become multidisciplinary.

problem-solving organizations. The disciplinary frontiers are the frontiers of our civilization. Only as long as they are vigorously explored will our future problem-solving capability be assured -- on campus or off. Meanwhile, universities have no track record as problem-solving organizations and should not be so regarded.

12. Increasingly disconcerting, to me, is the loss of faith in the belief that science is the principal instrument for alleviating the condition of man. Immediate allocation of all possible resources to the amelioration of domestic and international problems is demanded -- as if we already possessed all the information and understanding required or possible. Such sounds emanate from every campus and are occasionally reflected by those in the public arena who would pander to such sentiment. In the face of these pressures, it appears ever more necessary to educate those in authority to the ultimate social values of undirected fundamental research, an education which necessarily consists of recital of anecdotes. That would be a minor problem were it not for the fact that, to compensate, some scientists who should know better cannot resist the temptation to over-promise. Witness the behavior of those who have recently indicated that only sufficient funding stands between us and definitive therapy of neoplastic diseases.

13. But let me not exaggerate the plight of American science. Research in many disciplines proceeds with great vigor and sense of accomplishment. Federal funding for basic research has declined from fiscal year 1967 by perhaps 20% in constant dollars, from private sources by somewhat more. Since some laboratories may have been rather generously funded and there may even have been some marginal investigators whose loss from the system is small loss to society, of itself that decrement might not have been too serious.

However, this system, with earlier public and federal encouragement, has been operating so as to double the available scientific population in each decade. And still they come. The pipelines are still full; graduate student enrollments have not yet suffered significantly but it is no longer clear that they will find suïtable employment. Should that prove true, should there not be appropriate jobs for them, our country will have fallen off the track of true progress.

For the long term, declining undergraduate enrollments in science appear more serious; we shall badly need most of these young men and women one day, although it would be well to reduce annual output somewhat. Much as policy for fundamental research must be directed toward

the requirements of society a decade or more hence, so also must our policies for support of education in science -- which must not be blinded by transient episodes such as the current, temporary I trust, wave of technological unemployment, particularly on our West Coast.

We are now living through a transition phase from the time in which all major decisions affecting our national life were made in a free market economy to a time when, inevitably, most such decisions will be taken in the public sector of a mixed economy. That we are woefully unskilled in this art is evident in the disingenuous exclamations of governmental dismay when wholesale unemployment of technically trained individuals resulted from sharply decreased federal funding of applied research and development in the aerospace industry, when, patently, the government itself was known to be the only customer. I hope that this lesson has been learned and that such episodes will not recur. We sadly lack a national vision, much less plan, as to how we shall address our national technical capabilities to the battery of discernible problems, domestic and international, which demand technical solutions. Much of this effort must -- and will -- occur in private industry, but government must provide a sense of direction. My subsequent remarks will attempt to illustrate a few of these problems.

Health Care

I consider myself extraordinarily privileged to have witnessed at first hand the glorious development of biochemistry. But I also recognize how much more there is to be learned than is yet known. And that is precisely the point. One can fashion an impressive list of all those diseases for which research has already provided definitive, therapeutic or preventive measures. In the main, these are nutritional deficiencies, infectious processes, and endocrine disorders. The cost of the earlier research and the current costs of dealing with these diseases are trivial as compared with the social and financial costs when each was a major affliction of mankind.

In contrast, the diseases which currently take serious toll of humanity are those which are now understood insufficiently to offer a basis for definitive prevention or therapy. And it is the less than satisfactory, terribly costly palliative management of these diseases, utilizing what Ivan Bennett has termed "halfway medical technology," which is what one means by the "health care" for which the country clamors. How comparatively trivial are the costs of research!

But how long and difficult the task is. Is it not remarkable that, amid all the cries of irrelevance, no

attention has been paid to the fact that 1970 marked the abolition of a once devastating disease? Last year, for the first time in recorded history, not a single case of smallpox was reported anywhere in the world. That event may go unnoticed in political history, but in the real history of mankind it represents one of man's truly great triumphs over his ever-hostile environment.

I cannot, in good conscience, promise that research will do the same for cancer, heart disease, stroke or multiple sclerosis -- but I can promise that if we do not try, those afflictions will continue unchecked. Can there be a better investment of public funds?

The Environment

The fever pitch of national, indeed international, concern for the environment is a phenomenon which future historians must evaluate in the perspective of man's occupancy of our planet. The universal intensity of these feelings probably arises from the fact that, at some time, each of us feels threatened by environmental disaster or offended by unsightly cities or landscapes. And properly so. Yet, even now, man's effect on the general environment is trivial as compared to that of natural forces.

Consider the effects of climate, erosion of continental surfaces by rivers and streams, transpiration of vegetation, the emanation of the terpenes from pine and cedar trees which long ago led man to name regions of the Appalachians as the Blue Ridge and the Smokies. Consider the lovely landscapes of England which were fashioned in the last several centuries from primeval forests and exist by virtue of the otherwise abominable English climate. Or the magnificently tilled hillsides of France, Italy and Japan, all of which were fashioned by the hand of man. Or the great, rich loam of our own prairies -- the consequence of centuries in which the Indians burned over the native vegetation as a means to drive the buffalo; to say nothing of earthquakes, tidal waves, or landslides.

Man and nature have ever been altering the total environment. Yet, even now, our tragically blighted cities are cleaner and healthier than were urban agglomerates anywhere in the world until the middle of the last century. We have not suddenly begun to alter the environment. Our entirely justifiable concern arises from the logarithmic concatenation of our ever-increasing numbers,

our marvellously productive heavy industry and agriculture, and rapid growth of real per capita income, coupled with sensitive chemical analytical procedures which permit detection of contaminants in minute amounts, some of which -- like the mercury in the swordfish -- may well have been there all these years. The very affluence which generates environmental difficulty also permits us to direct our efforts toward its abatement, to consider reversing untoward processes which have been in train for many decades, only a few of which have yet attained genuinely crisis dimensions. Our problem is whether their solutions can be found and implemented in a free market economy when -- until now -- the environment has been a "free good," available at no cost to both producers and consumers.

Many, but not all current environmental problems can be handled reasonably well with available "off-the-shelf" technology. But we have not yet established the social mechanisms whereby to bear the costs or agreed on how to determine what we shall forego so as to do so. Meanwhile, my special plea is that we do not, out of a combination of emotional zeal and ecological ignorance, romanticizing "good old days" that never were, hastily substitute environmental tragedy for existing environmental

deterioration. Let us not replace known devils by insufficiently understood, unknown devils, as in the current trend to replace phosphate in detergents with inadequately evaluted substitutes such as soda. Some 4,000 individuals, largely housewives and children, were treated at poison control centers last year for having swallowed household detergents. With the new formulae, using washing soda instead of phosphate, all would have been subject to lye strictures of the throat. Is this wise? When, tragically, highly toxic parathion was substituted for some uses for too stable, but relatively innocuous, DDT, numbers of unsuspecting Americans were killed. Wise? The brute fact is that ecology is, as yet, a young, little developed science which requires much nourishment before it can adequately serve society. But ecology does insist on the complex inter-relatedness and stability of ecosystems. The lesson to those who would hurriedly attempt simplistic solutions to environmental problems is, as Landberg noted, "Use well before shaking!"

It seems strangely difficult to order national priorities. How remarkable that we should weigh air pollution from automobile tailpipes more heavily than the annual carnage on our highways -- 56,000 deaths and hundreds of thousands of injured last year -- or that we so easily ignore

the 15 tons of TNT equivalent for each man, woman and child on the face of the earth now reposing in the nuclear tips of the world's arsenals.

Perhaps, however, that is the solution. Were we to galvanize the governments of the world into an international effort to reverse the deterioration of the planetary environment, utilizing funds released by a moratorium in the arms race, we might also contribute to the cause of a stable peace. Surely the ultimate environmental catastrophe is nuclear warfare.

No aspect of the environment is more troubling than its international considerations. Massive preparations are underway to plan the U.N. Conference on the Human Environment in Stockholm, a year hence. Agreements will be sought among the industrialized nations concerning well publicized difficulties. But how shall we approach the so-called "developing nations." Whatever prospect of economic growth they may have is totally absorbed in the costs of population growth plus demanded environmental protection. No wonder they prefer to repeat our mistakes. Their choice appears to lie between environmental degradation or large scale importation of capital from the industrialized nations, without which they are doomed to remain the non-developing nations. How would you have your government respond at that Stockholm Conference?

Energy and Natural Resources

This country does not face an immediate natural resource crisis. Although coal mining is currently a distressed industry and we depend upon imports for 25 out of 32 strategic minerals, we have no current problems in satisfying our wants in these regards. But the analyses of this problem which I see invariably strike me as being short-sighted in that they fail to anticipate the day when currently less developed countries will want these minerals for their own purposes. So-called "long-term" projections extend to the year 2000 or even 2100 -- when I expect mankind to be walking the earth in the year 200,000. On that time scale, without exquisitely careful international planning, there may be insufficient quantities of any natural resource other than oxygen.

Is it not almost sinful that we burn petroleum as a source of energy, thereby denying our progeny of this unique raw material for chemical industry? Can mankind become wise enough to husband this unique resource before its exhaustion? Billions of years of a little understood process were required to accumulate our reserves of coal and oil. By what right are these to be consumed by just a few generations of man?

And yet, energy production and utilization lie at the heart of our civilization. Each of us cherishes his own personal transportation, and although we shall surely manage to reduce the air pollution engendered by the internal combustion engine, no truly acceptable substitute for pertroleum as a fuel source for an equivalent mode of personal transporation has yet become evident. And time is running out.

Equally perplexing is our attitude with respect to large-scale energy production. Electric power drives our civilization. For well known reasons, the projected increased demand for such power is unlikely to be met by combustion of fossil fuels -- which need be conserved, in any case. Hence, nuclear power plants, whether of the current variety, the breeder reactors under development or the ultimate of controlled fusion will soon become absolutely essential to our way of life -- since return to more primitive times is really unacceptable.

In part, this is because we are not really a consuming civilization, but a processing one, generating vast quantities of waste which demand disposal. Possibly, with sufficient ingenuity we shall devise means for recycling much of it, as already is done in the steel industry.

But that will, necessarily, require expenditures of yet more energy. Thermodynamics permits no way out of this dilemma. Hence, early resolution of the conflict between the suppliers of energy and the environmentalists is imperative; the quality of life is at stake. This difficult political decision must rest on an adequate, comprehensive, objective analysis of these problems. Unhappily, none is yet available.

My point, then, is that the requirements and opportunities for research germane to this assemblage of environmental, transportation, energy and natural resource use and waste disposal problems could profitably utilize the research attention of a great battery of scientific talent. But we have not yet agreed to do so, much less organized to undertake these tasks. Industry can do much, but leadership rests with the government.

Population

Our population problems do not arise out of concern for our ability to feed ourselves. At home they may arise, in part, from our inability to provide useful employment to a growing fraction of our fellows because the others will be so productive, as well as from the impact of our very affluence on the environment and supply of raw materials if future generations are to live as well as do

we. In the economically underdeveloped world, population growth is the deterrent to improvement in the quality of life. Ironically, it is almost sad to realize that, thanks to the "green revolution," Malthus was wrong. We shall almost certainly be able to feed a world population which is intolerably large by any other criteria.

Here again, research has scarcely begun. The first generation of mechanical and chemical means of contraception, remarkably successful as they have proved, will certainly not suffice. We yet require simpler, cheaper, safer, more reliable methods and these can derive only from better understanding of reproductive physiology. Even now, however, lack of acceptable social mechanisms to ensure their utilization is a principal impediment to population control. Nor should it be thought that the task of agricultural research is complete. On the contrary, this endeavor has no end; its very successes always bring yet more problems, witness the sudden spread of a corn blight last year.

Thus we stand at a strange crossroad. The pattern and quality of American life is largely the product of past research. In some of the very areas where, in the past, we have been most successful, the direction of future efforts is now in question. To be sure, some of the most exciting visions in the history of man, particularly those of molecular biology, have as yet found

little application. But they will. Whereas science is most capable when studying the infinitely large or the infinitesimally small, man's most serious problems lie in the as yet insufficiently comprehended range between. Physiology, psychology, developmental biology, sociology, and ecology, inter alia, are as yet too primitive for applied societal purposes, while the problems to which these disciplines might contribute grow ever more intense. And yet the research effort is said to be irrelevant.

The Planet as a System

The view of earth from space brought home how small our planet really is, and gave stimulus to what is becoming a new discipline -- systems analysis of the entire world biosphere. Such studies seek to understand, by computer modelling, utilizing as many parameters as can usefully be invoked, what the longer-term future of our planet may be. After adopting a set of arbitrary assumptions, models are constructed indicating future consequences of the sustained growth or decline of the world population, of the food supply, the energy supply, waste accumulation, etc. Sadly, these models indicate that, unless man changes the course of events, a cataclysm of some kind is in the offing sometime in the next century. This discipline is in its infancy.

Hopefully, it will yet mature sufficiently to become a useful guide to political action. If so, it may yet force adoption of a true world government. The few so engaged have assured themselves that we really do live in a period of sharp transition between the past and the future, in the sense that decisions taken in the next few years may make for irrevocable commitments concerning the future of mankind.

Peccei summarized it thus: "...the responsibility of controlling technology and through it of regulating the ecosystem itself, now rests on man... He must now take upon himself functions in the cycle of life which up to now were reverently considered to be the prerogative of nature or providence, and left to their inscrutable designs. The physical world and the biosphere are now so pervasively interfered with by man's actions that he has no other alternative but to accept the responsibility of being, himself, the enlightened manager of his terrestrial kingdom."

After the victory at El Alemein, Winston Churchill said, "This is not the end; it is not even the beginning of the end, but perhaps it is the end of the beginning." Perhaps it is. Hopefully, man himself has come to the end of his beginnings. If we are fortunate and wise, with your help, science may yet be the means to set man free.